Improving Impact Assessment

Increasing the Relevance and Utilization of Scientific and Technical Information

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6. Improving Predictive Performance and Usefulness of Biological Environmental Impact Assessment: Experimental Impact Studies and Adaptive Impact Assessment

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OVERVIEW

Environmental impact studies attempt to predict effects of impacting factors on a biological system by examining the system in its present unimpacted state. Consequently, the biological studies produced have poor predictive capabilities and are generally lengthy descriptions of the existing biological system. Simulation modelling can be used to focus selectively on important relationships between possible impacting factors and ecosystem variables. A number of methods can be used to simulate or perform the proposed development changes on an experimental basis (e.g., on simulation models, on physical model systems, on parts of the real system, in comparative studies, and in monitoring of actual developments) and, thus, improve the capability to predict impacts. Incorporation of Environmental Impact Assessment (EIS) into the management/decision-making process and its time horizon allows for revisions and re-evaluations of assessments as development proceeds and research results are produced. Examples of these approaches ~~will be~~ are drawn from studies on effects of a variety of coastal activities on biological resource systems, including salmon and oysters in British Columbia.

Assessment of biological impacts is perhaps the most emphasized aspect of current Environmental Impact Statements (EISs). Assessment usually attempts impact identification, magnitude estimation, and evaluation of importance. Whether those identification, estimation, and evaluation functions are performed at a qualitative or a detailed and/or quantitative level, the process is essentially one of prediction since it describes future states of the system being considered. EISs generally make predictions based on knowledge of the unimpacted system. That is, in fact, the objective of current Environmental Impact Assessment: to predict impacts before they actually occur.

Two critical issues must be raised about the

prediction function of EIA. The first issue that must be recognized is that there will always be (perhaps substantial) uncertainty. Therefore, EISs cannot make sure predictions; that must be planned for by interfacing impact assessment with management and decision making, thus providing for revisions of the EIA. The second issue is that the major approaches presently used to predict biological (and other) impacts are based on examination of the unimpacted system: they must be improved upon by using approaches that examine a simulation or other form of the post-impact system--which is a new and different system whose behavior is difficult or impossible to predict even with perfect knowledge of the unimpacted system. Examination of such simulated and/or experimental developments can be made for a number of different development alternatives within the same environment. Thus, it is possible to assess provisionally ways to enhance the desired positive effects of developments while diminishing the negative impacts.

IMPROVING IMPACT ASSESSMENT BY ADAPTING IT TO ONGOING MANAGEMENT

No form of study or analysis will allow certain (or even near-certain) impact prediction for most systems. There will be residual or major uncertainties in all situations as a result of biological complexity and the unknown nature of impact interactions. It is important to recognize and describe that uncertainty, to try to understand the basic functioning of the new (impacted) system, and to revise predictions as the system responds. Thus, EIAs that are one-time, pre-impact studies have little chance of contributing predictions that are reliable or useful for decision making on an ongoing basis. Unfortunately, existing institutional and decision-making arrangements (NEPA, CEQ, EARP, and many of their state/provincial and municipal counterparts) assume such a temporal arrangement for EISs and, thus, do not provide for incorporation of impact assessment into development and post-development phases of the management and decision-making process. There are opportunities within current arrangements, however, for special efforts and provisions to be made that incorporate monitoring programs and revised assessments into post-development management. These opportunities include specification of post-development monitoring and reassessment requirements in the terms of reference of an EIA, or in contractual arrangements, and efforts to incorporate impact assessment into management processes by working with government agencies and development proponents outside the formal EIA process. These efforts relax the (unattainable) requirement of certainty in EIA predictions and allow us to learn from our decisions and the system's responses (see Figure 6.1). Most of our efforts at the University

of British Columbia have been directed at incorporation of impact assessment into management programs of government agencies. For example, we assessed the impacts of the activities of the forest products industry, including transport and storage of logs in coastal waters, on the oyster resource and industry in British Columbia (Valiela, 1979a, 1979b). The assessment used a simulation model (see Figure 6.2) to make initial predictions of oyster growth and survival and oyster industry production depending on levels of log activities in oystering areas. Figure 6.3 is one of the scenarios examined. It illustrates the effect on the British Columbia production of oysters, using bottom culture, of gradually increasing the conflicts with the forest industry. As shown by the solid line, if conflicts remain at their present levels, and we assume that the rate of seeding is increased and good market demand continues, then production from bottom culture could be expected to double in the next twenty years. However, if there is a gradual increase in the conflicts with the forest industry, there would be no increase in production, as shown by the dashed line, in spite of other favorable conditions. On the other hand, concentration of oyster production in areas that might be given a protected-reserve status has considerable potential even in the face of generally increasing conflicts with the forest products industry. Figure 6.4 shows how oyster production by string culture might be increased over the next twenty years even with increasing conflict if just two highly productive areas (Baynes Sound and Malaspina, in this example) are protected by a reserve status.

The initial impact predictions discussed above were accompanied by management suggestions (e.g., make deals for selected high-priority oystering areas) and selected research suggestions (e.g., measure growth rate of oysters in a log storage area). As management and system responses proceed (e.g., some high-priority oystering areas are reserved; others are lost to forest-industry uses) and results of research emerge (e.g., growth of oysters to commercially usable sizes takes, let us suppose, six years in certain affected areas as opposed to four years in similar but unaffected areas), the prediction of impact on the productivity of the oyster industry can be reformulated or revised. Thus, the initial predictions of impact need not be highly certain but are useful in suggesting immediate management and research strategies leading to future improvements in predictive and planning performance. At the same time, the results of the research and the revised impact predictions can be used for evaluation of the initial EIA.

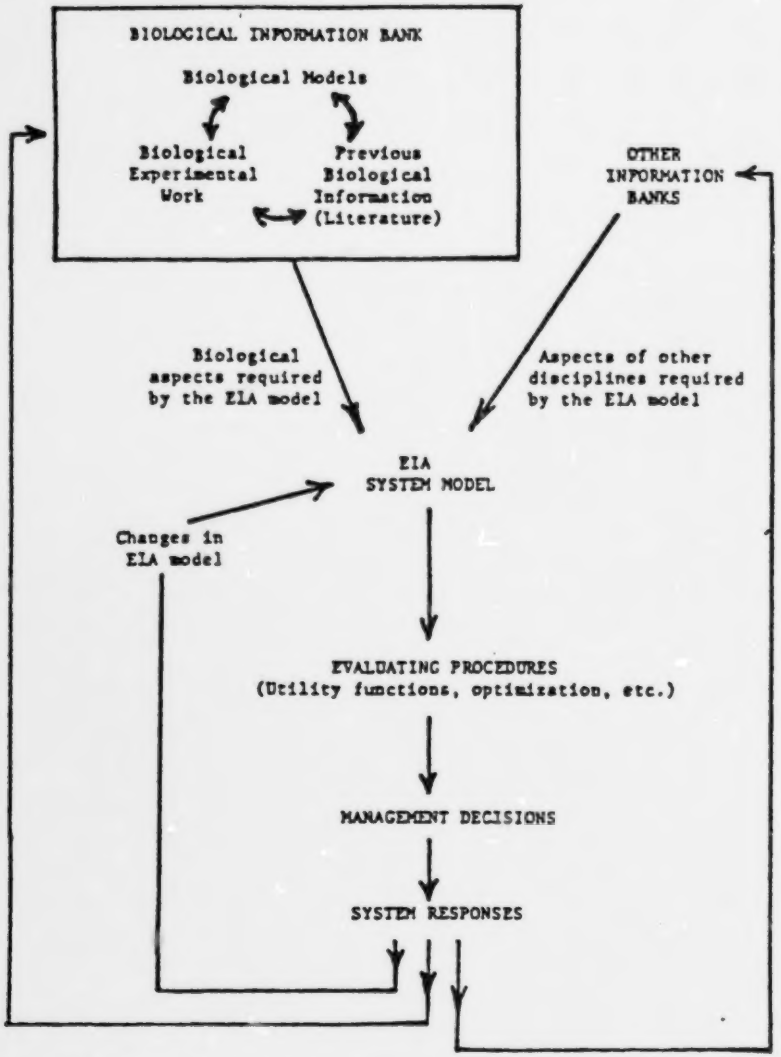
BIOLOGICAL INFORMATION BANK
Biological Models
Biological Experimental Work
Previous Biological Information (Literature)
OTHER INFORMATION BANKS
Biological aspects required by the EIA model
Aspects of other disciplines required by the EIA model
EIA SYSTEM MODEL
Changes in EIA model
EVALUATING PROCEDURES (Utility functions, optimization, etc.)
MANAGEMENT DECISIONS
SYSTEM RESPONSES

Figure 6.1 Diagrammatic representation of the input of biological information into an environmental impact assessment. Note that the term "information bank" is used in the general sense to designate the total information available from that discipline for use by the EIA. Note the direction of information flow indicated by the arrows and the various feedback loops. (Source: Ward, 1978)

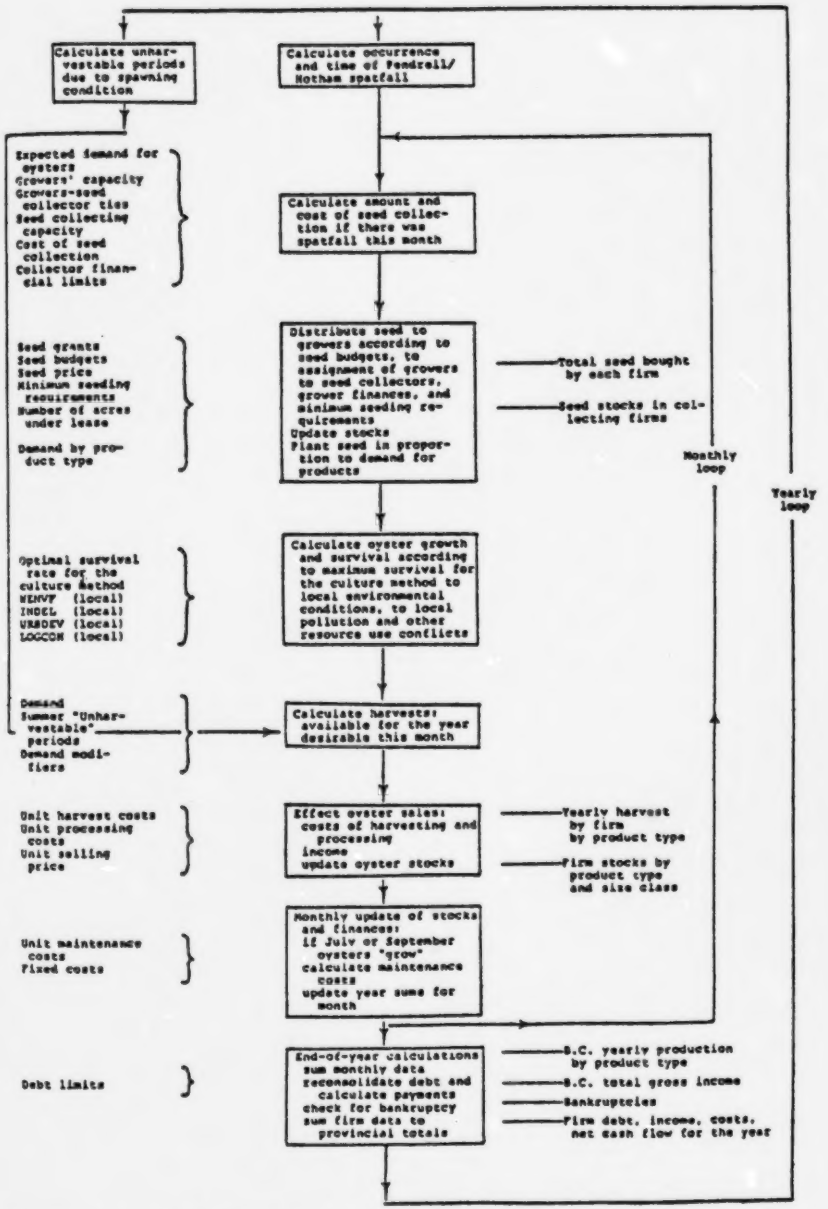
Calculate unharvestable periods due to spawning condition
Calculate occurrence and time of Pendrell/Hotham spatfall
Expected demand for oysters
Growers' capacity
Growers-seed collector ties
Seed collecting capacity
Cost of seed collection
Collector financial limits
Calculate amount and cost of seed collection if there was spatfall this month
Seed grants
Seed budgets
Seed price
Minimum seeding requirements
Number of acres under lease
Demand by product type
Distribute seed to growers according to seed budgets, to assignment of growers to seed collectors, grower finances, and minimum seeding requirements
Update stocks
Plant seed in proportion to demand for products
Total seed bought by each firm
Seed stocks in collecting firms
Monthly loop
Yearly loop
Optimal survival rate for the culture method
NEMVF (local)
INDEL (local)
URBDEV (local)
LOGCON (local)
Calculate oyster growth and survival according to maximum survival for the culture method to local environmental conditions, to local pollution and other resource use conflicts
Demand
Summer "Unharvestable" periods
Demand modifiers
Calculate harvests available for the year desirable this month
Unit harvest costs
Unit processing costs
Unit selling price
Effect oyster sales: costs of harvesting and processing
income
update oyster stocks
Yearly harvest by firm by product type
Firm stocks by product type and size class
Unit maintenance costs
Fixed costs
Monthly update of stocks and finances: if July or September oysters "grow" calculate maintenance costs
update year sums for month
Debt limits
End-of-year calculations sum monthly data reconsolidate debt and calculate payments check for bankruptcy sum firm data to provincial totals
B.C. yearly production by product type
B.C. total gross income
Bankruptcies
Firm debt, income, costs, net cash flow for the year

Figure 6.2 Flow diagram of the oyster production simulation model. The main inputs are on the left of the calculation boxes; the main outputs are on the right. The center of the diagram portrays the impacts of log-handling activities (LOGCON) on oyster growth and survival and, thus, on oyster production outputs further down. The effects of a range of alternative policies can be explored by varying the actions taken. (Source: Valiela, 1979b)

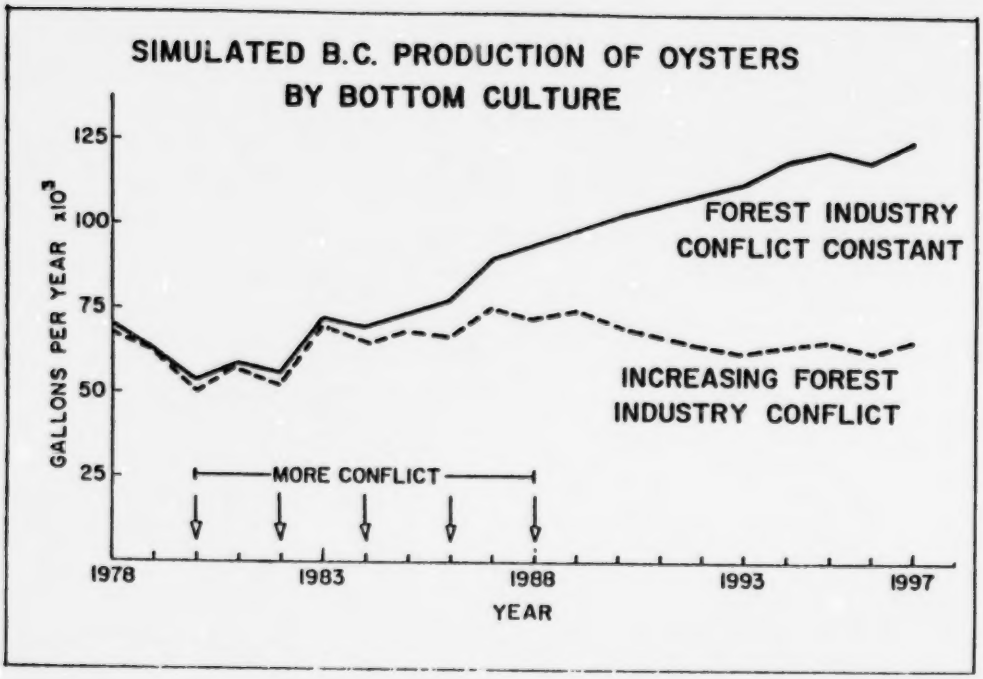

Figure 6.3 Simulated production of oysters by bottom culture in British Columbia assuming present levels (solid line) and moderate gradual increases in conflicts (dashed line) with the forest products industry. Other conditions are assumed to be favorable within realistic limits. (Source: Valiela, 1979b)

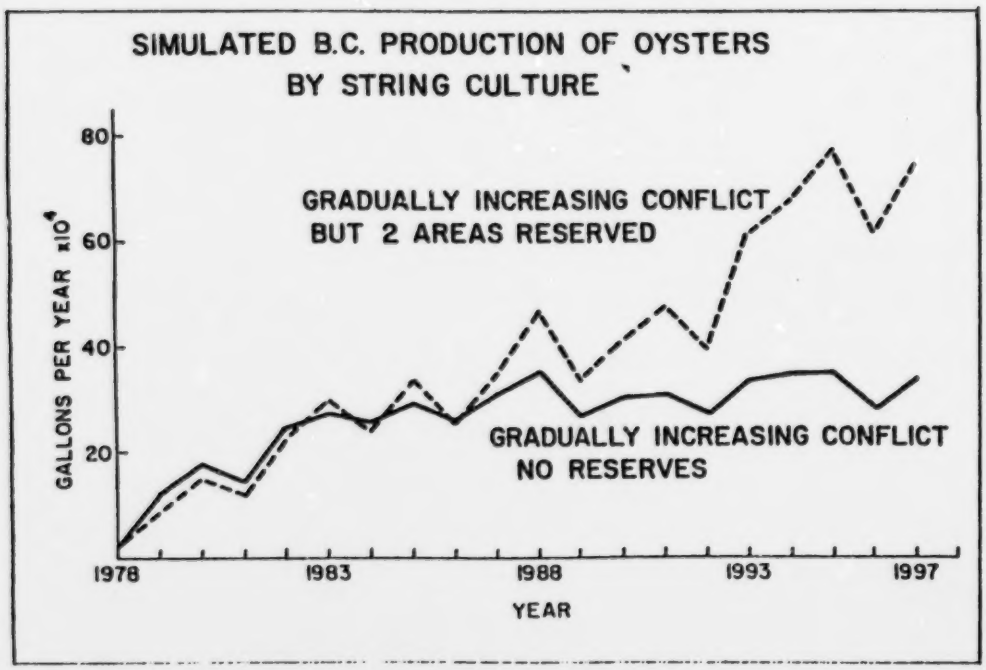

Figure 6.4 Simulated production of oysters by string (off-bottom) culture in British Columbia assuming moderate gradual increases in conflicts with the forest industry, other conditions being favorable, and no protective reserve status for any areas (solid line) and reserves in two highly productive areas (dashed line). (Adapted from Valiela, 1979b.)

IMPROVING ASSESSMENT OF IMPACTS BY STUDYING THE IMPACTED SYSTEM

The major approaches currently used to predict biological as well as nonbiological impacts are based on the assumption that descriptive information in the present state allows prediction of system behavior in changed (impacted) states. The principal terms of reference for most biological impact studies are usually of the form(s): "What will be the effects of factor or development X on biological components A, B, . . ., N?" or "What will be the effects of factor or development X on ecosystem Y?" The response of the impact assessor is to review various aspects of the proposed development, examine the existing biological system, and prepare a report presenting speculations as to the possible effects of development X, or of several forms of development X, on the described components or ecosystem. The examination of the existing biological system usually employs either the "busy-taxonomist" approach or the "information-broker" approach. In both, literature and other researchers are surveyed to obtain descriptive information about the biological components of the ecosystem in question. This is the major emphasis in the "information-broker" method. For the "busy taxonomist," the next and most important step is field-survey sampling, often carried out to the extent allowed by the time specified in the terms of reference. The survey sampling examines the distribution and abundance of the biological components and the values of physiochemical factors present in the ecosystem. Often a considerable volume of taxonomic work is involved. In some of these studies, there is an attempt to investigate functional characteristics--but in the unimpacted state of the system. Voluminous descriptions and data tabulations often result. In both approaches, a (lengthy) report is prepared, containing guesses as to how the ecological system might respond to each development alternative. These guesses are based on some conceptual model of how the new (impacted) system will function. There are often suggestions for (expected) impact mitigation, but seldom provisions for post-monitoring or reassessment of impacts either at a future time or on some representation of the impacted system.

Even within current EIA arrangements, usefulness and predictive ability of EISs can be greatly improved by: (1) beginning the EIS by rapid construction of a much more explicit model of the impacted system rather than ending the EIS by construction of an ill-defined model of the new system; (2) using the model to formulate hypotheses about biological effects of the proposed development; (3) performing the proposed development on an experimental basis (on simulation models, on physical-model systems, on parts of the system, or in comparative studies) to test the impact predictions generated by the initial model; and

(4) modifying the model and proposing expected impacts, along with important assumptions, key data, or analysis needs, and applicability limitations.

MODELLING AND HYPOTHESIS FORMULATION

As previously mentioned, all approaches to impact assessment involve some conceptual (mental, implicit) model of the impact system and involve a large number of implicit assumptions. The mental models are usually not sufficiently explicit to discriminate effectively the relevant vs. the irrelevant issues or to recognize and examine assumptions, certainties, and uncertainties. Further, the conceptual models tend to be constructed at the end of the EIS. Meanwhile, the bulk of the EIS effort and time has been devoted to examination of the unimpacted system.

Explicit modelling performed early in the EIS can be used to focus the study on the impacted system, to discriminate relevant from irrelevant or less crucial questions that may be pursued in the EIS, to focus selectively on important relationships between impacting factors and ecosystem variables, and to identify clearly assumptions, uncertainties, and important future information needs. A large assortment of modelling activities and types is available. (Some are compared and discussed in Holling, 1978.) In general, the more explicit (explicit does not mean detailed) we are forced to be by the modelling activity, the better. The model may be at the conceptual, verbally descriptive level, a fully computerized simulation model, or something between these two categories (e.g., matrix methods for impact identification). The model should include the proposed development factor(s) as one interacting component. This involves guessing at development effects, but in an explicit systematic framework and in the context of causal and functional pathways in the biological system. Based on this analysis, we can list predicted biological effects of the development factor(s) and identify processes and variables likely to be crucial to model outcome and to the function of the biological system.

The question of whether to attempt a computerized simulation model for a specific situation is a complex one that arises with each new (and always different) environmental impact study. A full discussion of decision criteria for computerization is given in Munn (1975). In general, matrix impact identification methods are useful for screening but not for generating predictions. Qualitative simulation models can help to construct a trial dynamic model and sometimes to experiment with alternative policies, but they are not useful for guiding research to be done in an EIS whether or not the data are good--unless there is no way to describe the basic features of the assessment (impacting factors and

biological elements) and the relationships between the basic features--and are good for making predictions when the data are good (Holling, 1978). In some cases, the data (or, rather, the information, since qualitative aspects are often most important) are far better than initially suspected and can be utilized by bringing experts or managers familiar with the system into a workshop situation. In such situations, we can extract unpublished data and experientially aided guesses as to alternative functional pathways.

Application of simulation modelling to examine effects of developments and management actions on salmon systems in British Columbia provides examples of the benefits that can be derived from explicit modelling even when the data are poor and the model is essentially qualitative (whether or not it is computerized) and of the benefits that can be derived from making numerical predictions of effects even if (sometimes, especially if) the predictions are in error. One simulation model was constructed to examine consequences of marsh habitat loss through developments for salmon populations of the Fraser River (Dorcey et al., 1978; Valiela and Kistritz, 1979). It was known that juvenile salmon migrating to sea were sometimes found in Fraser marsh areas. Would the disappearance of all or some of those marsh areas affect the salmon productivity of the Fraser? It was clear from the outset that the biological system was too complex (there are five species and numerous races of salmon in the Fraser; they have a complex life history utilizing many habitats; they are affected by human activities in many ways and many places; and they number in the hundreds of millions of fish as juveniles) and the existing information inadequate to describe the major functional attributes of the marsh-salmon system. However, decisions on developments affecting or removing marshes must be made now and we cannot expect the mammoth investment in research that would be involved in understanding the entire salmon system.

As a result of explicit modelling, even at this level of information deficiency, we were able to isolate two critical research priorities, from a huge domain of possible questions, that are of greatest immediate use in evaluating the importance of marsh habitats to salmon. One important question emerged from what was included in the model (see Figure 6.5). In describing the utilization of marsh habitats by young salmon, we had only guesses on whether the fish actually resided in the marsh or simply passed through: in addition, we could not describe whether other estuarine or coastal habitats could be used by the marsh residents if they were deprived of marsh habitats. Thus, a first research priority was to determine residence time in marsh and nonmarsh habitats. Without residence, it is unlikely that survival of the fish would be greatly affect by marsh disappearance. We

have now determined that chinook, and to a lesser extent chum, show significant marsh residency in the Fraser (Levy et al., 1979).

The second research priority was identified by what was excluded from the model. We realized we could not model the entire life history of the salmon, since such a model would be very large and complex and the features of marine stages are even less well known than are those of estuarine phases. However, it was also realized that, even if numerous juveniles had extended residence periods in marsh habitats, those habitats would still not be vital to stock production unless the marsh residents constituted a significant proportion of successful returning adults (i.e., their marsh residency contributes to survival until they return to spawn). Thus, the second research priority indicated was feasibility of growth-pattern analysis (in otoliths or in scales) to differentiate marsh residents from nonmarsh residents when returning as adults. Thus, even though the salmon-marsh model produced predictions of juvenile salmon numbers that were no doubt grossly in error because of the number of assumptions made in the absence of data, the modelling effort clearly identified major areas of data deficiencies (see Table 6.1) and allowed specification of high-priority questions from a huge set of possible questions.

Another modelling effort on a salmon system in British Columbia showed that making numerical predictions with a model can be of value even if the predictions are in error. The model was an attempt to predict salmon stock sizes under different fishing regimes in Georgia Strait, British Columbia (see Argue et al., in preparation; Holling, 1978, Chapter 12). The model included assumptions and data-based estimates of the catches of various fishing fleets as well as of other relationships. When model predictions of populations of chinook and coho salmon were examined, there was consistent overestimation when compared to available data. Going back to assumptions and parameters and calculating new predictions for alternative assumptions showed that the estimate of the sport catch for these two species must have been seriously underestimated (Walters, personal communication). This discovery led to recommending data collection on that issue; data recently collected show that for some stocks the sport catch of chinook and coho may be twice as high as previously thought. This information is very important to develop new management regulations for sport and commercial fishing in the area. Thus, both the modelling activity and examination of model predictions can help identify very specific high-priority data needs and eliminate general, nondirected, expensive, and time-consuming data collection programs.

It should be noted that equally expensive, time-consuming, and overly complex modelling programs can result if conscious efforts are not made to restrict

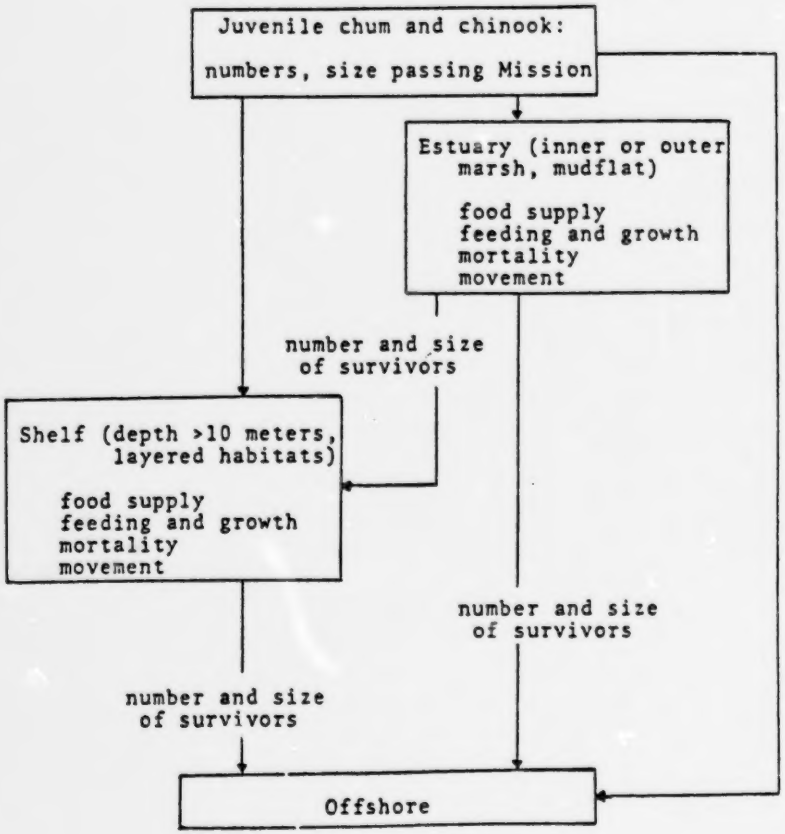

Figure 6.5 Simplified flow diagram of estuarine utilization by chum and chinook juveniles. (Source: Valiela and Kistritz, 1979)

TABLE 6.1
Key uncertainties suggested by modelling the consequences of marsh habitat loss for salmon populations of the Fraser River (from Valiela and Kistritz, 1979)

Distribution and Migration
1. Residence time by habitat and cues for movement
2. Size and weight of downstream migrants
3. Timing of downstream migration
4. Determinants of habitat selection
- food supply
- osmoregulatory limitation
- predation avoidance
- estuarine holding
5. Density-related behavior
Food Supplies
1. Approach to conceptualization of the complex community of food groups
2. Selected baseline seasonal patterns for food groups
3. Major factors used in food selection by salmon juveniles
4. Effects of changes in salmon predation on dynamics of major food organisms
Feeding and Growth
1. Perception and rate of effective search
2. Importance of fish-to-fish interactions
3. Determinants of maximum rations
4. Effects of water quality parameters on feeding rates, prey selection
5. Short-term feeding periodicities: time budgets
Mortality Agents
1. Behavioral implications of stress situations
2. Size-selective mortality by agent type
3. Effect of vulnerability to mortality agents relative to feeding-time budgets
4. Survey of actual and potential predators and estimates of their potential ingestion rates of salmon fry; aggregation behavior of predators
5. Switching of prey onto salmon

models to reasonable sizes. (The number of assumptions increases much faster than the number of relationships represented; the compounding-of-errors effect can thus be very large.) In general, it should be possible to construct initial models for impact assessment analysis and hypothesis generation in less than a week of concentrated effort by a team of experts and modellers (for techniques, see Munn, 1975; Walters, 1974). If a smaller or less-diverse group is involved, and if accurate predictions are desired, longer periods may be necessary. If qualitative, explicit models are constructed, usually a day or two will suffice. Generally, even the most ambitious models of well-known systems should be limited to, at most, a few hundred relationships; generally much less than that is desirable for environmental impact purposes. There also exist mechanisms to help delimit what is included in a model (see Munn, 1975, pp. 74-79).

EXPERIMENTAL STUDY OF IMPACTED SYSTEMS OR THEIR MODELS

So far I have attempted to show a variety of useful aspects (e.g., conceptualization, explicitness of assumptions, and identification and ranking of uncertainties) of explicit modelling to examine the impacted system in an EIS. Prediction generation is only one of these aspects, although it is commonly assumed to be the only objective of mathematical modelling. Nevertheless, models will generate predictions in an EIS and it is a valid question to ask, "How good are these predictions?" One useful approach is to test them empirically and, depending on the outcome, to use the experimental results to modify our models and predictions or to gain confidence in our conceptualization of the system and expected impacts.

Having used explicit systematic modelling to focus selectively on important relationships between possible impacting factors and ecosystem variables, we should have a set of hypotheses or predictions to test (and a set of variables to measure as outcome indicators). A number of methods can be used to simulate or perform the proposed and alternative development changes on an experimental basis: on simulation models, on physical model systems, on parts of the real system, in comparative studies of systems already affected, and in monitoring of actual developments. In many situations, controlled experimental versions of developments can be performed on mathematical or physical models, on limited parts of the real system, and in comparative studies. These experimental impact studies, in combination with modelling analysis to guide the experimentation and selected laboratory studies to test specific hypotheses, can be very powerful and efficient and have been discussed and exemplified elsewhere (Ward, 1978).

An appropriate issue to discuss here is the set of

situations in which, because of the all-or-none nature of the project (e.g., construction of a dam) or because of the large size and complexity of the system affected (e.g., disappearance of marsh habitats from the Fraser estuary), it is difficult or impossible to create appropriate (realistic) experimental environments without simply allowing the full-scale development to proceed. In the case of marsh disappearance in the Fraser estuary, it is unlikely that this experiment will be made. The risks involved are, in my opinion, seen as too great and too costly for such a decision to be made. There will probably be, however, some limited but further marsh loss due to developments.

An immediate challenge that we face in our research is to design a marsh-loss experiment in some much smaller system (perhaps capitalizing on an actual development) and to show that the results are extrapolatable to the situation in the Fraser estuary. Confidence in the extrapolation can only be bolstered by congruent evidence from a variety of sources. For example, if otolith pattern analysis shows marsh residents are an important component of returning chum and chinook populations in the Fraser, if simulation models indicate dependency on marsh residence for survival of some stocks of chum and chinook, and if a marsh-destruction experiment in a smaller estuarine system leads to reduction or disappearance of chum and chinook stocks in that system, we could be fairly confident that destruction of marsh habitats in the Fraser estuary would have a similar effect. On the other hand, lack of consensus among these various sources of evidence would indicate that we must revise our models about the marsh dependency of Fraser chum and chinook.

CONCLUSIONS

The challenge for developing technologies for biological EIA is not necessarily to develop increasingly complex and sophisticated methodologies, although some of these can be profitably used in combination with other approaches if guided by the needs of the EIA rather than by the technician's fondness for the methodology. The challenge is, rather, to have at our disposal a variety of methods and approaches that can be used according to the needs of the EIA and that help us to streamline, increase the predictive power, and enhance the management and decision-making usefulness of biological EISs. At the heart of such a strategy are the issues of concentration on system conceptualization before any empirical efforts are made, study of the impacted system in some form, experimental vs. descriptive empirical efforts, simultaneous use of a variety of approaches to enhance consensual confidence, and incorporation of EIA into the management/decision-making process to allow for revisions and re-evaluations of assessments as developments proceed

and new decisions must be made. All of these issues also emphasize our recognition that we cannot produce EISs that are perfect predictors of impacts but, rather, assessments that help us make decisions while we continue to explore the limitations and uncertainties of those assessments.

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